KEY to STEEL
The World's Most Comprehensive STEEL Database





In a Hurry?
Click here to check out Quick Richmedia Tour
» PLAY MOVIE

You want to master the world of nonferrous metals?
KEY to NONFERROUS

# Welding Ultra-High-Strength Steels

**Abstract:**
The term **high-strength steel** is often applied to all steels other than mild low-carbon steels. The steels which have yield strength over 560 MPa are sometimes called the **ultra-high-strength steels** or **super alloys**.
The groups of steels that fall into this category are:

- Medium-carbon low-alloy hardenable steels.
- Medium-alloy hardenable or tool and die steels.
- High-alloy hardenable steels.
- High-nickel maraging steels.
- Martensitic stainless steels.
- Semi austenitic precipitation-hardenable.

The term **high-strength steel** is often applied to all steels other than mild low-carbon steels. The steels which have yield strength over 560 MPa are sometimes called the **ultra-high-strength steels** or **super alloys**.

The groups of steels that fall into this category are:

- Medium-carbon low-alloy hardenable steels
- Medium-alloy hardenable or tool and die steels
- High-alloy hardenable steels
- High-nickel maraging steels
- Martensitic stainless steels
- Semi austenitic precipitation-hardenable stainless steels

## Medium-Carbon Low-Alloy Hardenable Steels

The best-known steels in this class are **AISI 4130** and **AISI 4140** steels. Also in this class are the higher-strength **AISI 4340** steel and the **AMS 6434** steel. These steels obtain their high strength by heat treatment to a full martensitic microstructure, which is tempered to improve ductility and toughness.

Tempering temperatures greatly affect the strength levels of these steels. The carbon is in the medium range and as low as possible but sufficient to give the required strength. Impurities are kept to an absolute minimum because of high-quality melting and refining methods.

These steels are available as sheets, bars, tubing, and light plate. The steels in this group can be mechanically cut or flame cut. However, when they are flame cut they must be preheated to 316°C. Flame-cut parts should be annealed before additional operations in order to reduce the hardness of the flame-cut edges.

These steels are suitable for welding only when they are in the annealed or normalized condition. After welding, they have to be heat treated to obtain the desired strength. The gas tungsten arc, the gas metal arc, the shielded metal arc, and the gas welding process are all used for welding these steels. The composition of the filler metal is designed to produce a weld deposit that responds to a heat treatment in approximately the same manner as the base metal.

In order to avoid brittleness and the possibility of cracks during welding, relatively high preheat and interpass temperatures are used. Preheating is in the order of 316°C. Complex weldments are heat treated immediately after welding.

Aircraft engine parts, aircraft tubular frames, and racing car frames are made from **AISI 4130** tubular sections. These types of structures are normally not heat treated after welding.

### Medium-Alloy Hardenable Steels

These steels are used largely in the aircraft industry for ultra-high-strength structural applications. They have carbon in the low to medium range and possess good fracture toughness at high-strength levels. In addition, they are air hardened, which reduces the distortion that is encountered with more drastic quenching methods. Some of the steels in this group are known as **hot work die steels** and another grade has become known as **5Cr-Mo-V aircraft quality steel.** These steels are available as forging billets, bars, sheet, strip, and plate.

There is another type of steel in this general class which is a medium-alloy quenched and tempered steel known as **high-yield** or **HY 130/150**. This type of steel is used for submarines, aerospace applications, and pressure vessels, and is normally available as plate. This steel has good notch toughness properties at 0°C and below. These types of steels have much lower carbon than the grades mentioned previously.

When flame cutting or welding the aircraft quality steels, preheating is absolutely necessary since the steels are air hardening. A preheating on 316°C is used before flame cutting and then annealed immediately after the flame-cutting operation. This will avoid a brittle layer at the flame-cut edge, which is susceptible to cracking.

These types of steel should only be welded in the annealed condition. The steel should be preheated to 316°C and this temperature must be maintained throughout the welding operation. After welding, the work must be cooled slowly. This can be done by post heating, or by furnace cooling. The weldment is then stress relieved at 704°C and air cooled to obtain a fully tempered microstructure suitable for additional operations. It is usually annealed, after all welding is done, prior to final heat treatment. The filler metal should be of the same com-position as the base metal. The gas tungsten arc and gas metal arc processes are most widely used. However, shielded metal arc welding, plasma arc, and electron beam welding processes can be used.

The medium-alloy quenched and tempered high-yield strength steels are usually welded with the shielded metal arc, gas metal arc, or the submerged arc welding process. The filler metal must provide deposited metal of a strength level equal to the base material. In all cases, a low-hydrogen or no-hydrogen process is required.

For shielded metal arc welding the low-hydrogen electrodes of the **E-13018** type are recommended. Electrodes must be properly stored. In the case of the other processes, precautions should be taken to make sure that the gas is dry and that the submerged arc flux is dry. By employing the proper heat input-heat output procedure yield strength and toughness are maintained. Preheating should be at least at 38°C for thinner materials. For heavier materials preheating temperature has to be higher.

The heat input should be such that the adjacent base metal does not become overheated while the heat output is sufficient to maintain the proper microstructure in the heat-affected zone. There may be some softening in the intermixing zone. The properties of welded joints that are properly made will be in the same order as the base metal. Subsequent heat-treating is usually not required or desired.

### High-Alloy Hardenable Steels

The steels in this group develop high strength by standard hardening and tempering heat treatments. The steels possess extremely high strength in the range of 1240 MPa yield and have a high degree of toughness. This is obtained with a minimum carbon content usually in the range of 0.20%; however, these steels contain relatively high amounts of nickel and cobalt, and they are sometimes called the **9 Ni-4 Co** steels. These steels also contain small amounts of other alloying elements.

They are normally welded in the quenched and tempered condition by the gas tungsten arc welding process. No post-heat treatment is required. The filler metal must match the analysis of the base metal.

### High-Nickel Maraging Steels

This type of steel has relatively high nickel, and low carbon content. It obtains its high strength from a special heat treatment called maraging. These steels possess an extraordinary combination of ultra-high-strength and fracture toughness and at the same time are formable, weldable, and easy to heat treat. There are three basic types: the steels with 18% nickel, 20% nickel, and 25% nickel. These steels are available in sheet, forging billets, bars, strip, and plate. Some are available as tubing.

The extra special properties of these steels are obtained by heating the steel to 482°C and allowing it

to cool to room temperature. During this heat treatment all of the austenite transforms to martensite. The heating time at the 482°C temperature is extremely important and usually is in the range of three hours. The steels derive their strength while aging at this temperature in the martensitic condition and for this reason are known as maraging steels.

These steels are supplied in the soft or annealed condition. They can be cold worked in this condition and can be flame cut or plasma arc cut. Plasma arc cutting is preferred.

These steels are usually welded by the gas tungsten arc or the gas metal arc welding process. The shielded metal arc and submerged arc process can also be used with special electrode-flux combinations. The filler metal should have the same composition as the base metal. In addition, the filler metal must be of high purity with low carbon. Preheat or postheat is not required; however, the welding must be followed by the maraging heat treatment which produces weld joints of an extremely high strength.

### Martensitic Stainless Steels

These steels are of the straight chromium type, such as **AISI 420**. They contain 12-14% chromium and up to 0.35% carbon. This composition combines stainlessness with high strength. Numerous variations of this basic composition are available, all of which are in the martensitic classification.

This type of steel has been used for compressor and turbine blades of jet engines and for other applications in which moderate corrosion resistance and high strength are required. The strength level of these steels is obtained by a quenching and tempering heat treatment. They can be obtained as sheet, strip, tubing, and plate. The compositions are also used for castings. These steels can be heat treated to strengths as high as 1750 MPa yield strength.

These stainless steels can be flame cut by the powder cutting system normally used for flame cutting stainless steels. They can also be cut with the oxy-arc process. Flame cutting should be done with the steel in the annealed condition. Most grades should be preheated to 316°C because they are air hardenable. They should be annealed after cutting to restore softness and ductility. These materials can also be cold worked in the annealed condition.

The martensitic stainless steels can be welded in the annealed or fully hardened condition, usually without preheat or postheat. The gas tungsten arc welding process is normally used. The filler metal must be of the same analysis as the base metal. Following welding the weldment should be annealed and then heat treated to the desired strength level.

### Semiaustenitic Precipitation-Hardenable Stainless Steels

The steels in this group are chrome-nickel steels that are ductile in the annealed condition but can be hardened to high strength by proper heat treatment. In the annealed condition the steels are austenitic and can be readily cold worked. By special heat treatment the austenite is transformed to martensite and later a precipitant is formed in the martensite. The outstanding extra high strength is obtained by a combination of these two hardening processes.

The term semi austenitic type was given these steels to distinguish them from normal stainless steels. They are also called **precipitation hardening steels** or **PH steels**. The heat treatment for these steels is based on heating the annealed material to a temperature between 927°C and 954°C, followed by a tempering or aging treatment in the range of 454-593°C. These steels are available as billets, sheets, tubing, and plates.

These steels are normally not flame cut. Welding is performed using the gas tungsten arc or the gas metal arc welding process. The shielded metal arc welding process is rarely used. The filler metal should have the same composition as the base metal. No preheat or postheat is required if the parts are welded in the annealed condition. After welding, the steel has to be heat-treated to develop optimum strength levels.

However, there is a loss of joint strength due to heating of the heat-affected zone above the aging temperature. In view of this, it is not possible to produce a 100% efficient joint. Extra reinforcing must be utilized to develop full-strength joints. These steels are also brazed using nickel alloy filler metal.

When welding on any of these high-strength steels, weld quality must be of the highest degree. Root fusion must be complete, and there should be no undercut or any type of stress risers. The weld metal should be free of porosity and any weld cracking is absolutely unacceptable. All precautions must be taken in order to produce the highest weld quality.

Home | Site map | Terms of Use | Key Benefits | How it Helps | Fact Sheet | Multiuser | Key to Metals | Key to Nonferrous Metals

© 1999-2006 Key to Metals Group & INI International. All Rights Reserved.